DOCUMENT RESUME

ED 385 194 HE 028 460

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TITLE The Explanation of Encapsulating Concepts by Medical Experts, Clerks and Advanced Students.
PUB DATE Apr 95
NOTE 11p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, April 18-22, 1995).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Cognitive Processes; *Experience; Foreign Countries; *Graduate Medical Students; Higher Education; *Knowledge Level; Knowledge Representation; Medical Education; *Physicians; *Thinking Skills
IDENTIFIERS Experts; *University of Limburg (Netherlands)

ABSTRACT

This study sought to discover differences in knowledge and knowledge organization between medical students and physicians. A total of 4 fourth-year students who had completed their pre-clinical courses, 4 fifth-year students who had just finished their internship in internal medicine, and 4 internists with an average of 20 years of experience were required to explain 20 central clinical concepts in 2 minutes. The results showed that the quality and elaborateness of the explanations linearly increased with level of experience. Further, it was found that more experienced subjects had easier access to their knowledge. The study concluded that expert physicians have access to more detailed and coherent knowledge than medical students in unfolding their encapsulated knowledge structures, and that medical students quickly acquire and restructure knowledge during internships. An appendix provides an outline of the task questions. (Contains 15 references.) (MDM)

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The explanation of encapsulating concepts by medical experts, clerks and advanced students

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The present study aimed to discover differences in knowledge and knowledge organisation between students, clerks and physicians. Subjects were required to explain 20 central clinical concepts in 2 minutes to the experimenter. The results showed that the quality and elaborateness of the explanations linearly increased with level of expertise. Further, it was found that more experienced subjects had easier access to their knowledge. It was concluded that expert physicians have access to more detailed and coherent knowledge than students in unfolding their encapsulated knowledge structures, and that clerks quickly acquire and restructure knowledge during the internships.

In the development from medical student to expert physician clusters of detailed biomedical knowledge become encapsulated into more comprehensive, higher order concepts (e.g. Schmidt & Boshuizen, 1992; 1993a). The extensive declarative knowledge base which students build up in the pre-clinical course of their training consists of in-depth knowledge about the normal and pathological functioning of the body, extended with clinical knowledge about epidemiology, clinical features, diagnosis and treatment of diseases. The greater part of this knowledge is abstract knowledge, in this sense that it is not experienced in real practice but rather acquired from textbooks and lectures. During the clinical rotations when students have to deal with real patients, they experience the variability in which diseases manifest themselves, the diagnostic methods applied, the practice of therapy and the way the medical staff solve medical problems. This newly acquired knowledge need to be integrated with the present mass of biomedical knowledge into a coherent entity. It is in this phase of medical study that the restructuring of knowledge in the form of encapsulation is starting to take place. Repeated application of knowledge in diagnosing and treating patients will result in the encapsulation of elaborate knowledge structures into a more limited number of highly inclusive concepts that have the same interpretative power as the original elaborate structure. Encapsulation of

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knowledge enables physicians to rapidly process medical cases which is necessary for the desired efficiency in daily practice. For advanced medical students who start to participate in this daily practice efficiency requirements will be an extra stimulus to speed up processing by encapsulation.

Support for knowledge encapsulation was provided by on-line studies of diagnostic reasoning (Boshuizen & Schmidt, 1992; Joseph & Patel, 1990; Lemieux & Bordage, 1986), post-hoc causal explanation studies (Kaufman & Patel, 1988; Patel & Groen, 1986; Patel, Groen, & Scott, 1988; Schmidt & Boshuizen, 1993b; Van de Wiel, Boshuizen, & Schmidt, 1994a) and clinical case recall studies (Boshuizen, 1989; Patel & Medley-Mark, 1986; Schmidt & Boshuizen, 1993b; Van de Wiel, Boshuizen, & Schmidt, 1994b). The on-line clinical reasoning studies found a lack of biomedical reasoning in think-aloud protocols of experienced physicians as compared to the protocols of students with an intermediate level of expertise. In addition, the post-hoc explanation studies demonstrated that expert physicians gave less extensive, although more coherent pathophysiological explanations of the signs and symptoms in a case than advanced students. And finally, clinical case recall studies showed that experts recalled less case information, but produced more high-level inferences than intermediate students. Examples of the high-level inferences made by internists in a case of acute bacterial endocarditis are septic syndrome, thrombo-emboli and affected heart valve (Schmidt & Boshuizen, 1993b), which not only subsume considerable propositions from the original text, but also refer to and encapsulate the underlying pathophysiological structures. The same encapsulating concepts were also found in the experts pathophysiological explanations of that case.

Boshuizen & Schmidt (1992) already argued that the encapsulated knowledge is not lost, but whenever necessary available through unfolding of the encapsulated knowledge structure. Using a combined think-aloud and post-hoc explanation methodology on a case of pancreatitis, it was shown that experts have more in-depth biomedical knowledge than novices and subjects at intermediate levels of expertise. In addition, a priming experiment in which subjects were given the opportunity to activate their knowledge on endocarditis demonstrated that experts generated more knowledge than advanced students (Schmidt & Boshuizen, 1993b).

The present experiment was designed to probe the content and organization of encapsulating concepts directly. Subjects of three levels of expertise were stimulated to unfold a number of encapsulating concepts by explaining them in detail to the experimenter. We expected that expert physicians show more integrated, coherent and elaborate knowledge than students when they are directly probed to unfold the encapsulating concepts. Furthermore, we expected that clerks during an internship are strongly stimulated to acquire and restructure knowledge resulting in considerably better explanation protocols compared to those of pre-clinical students.

Method

Subjects. Subjects were 12 students and physicians of the University of Limburg: 4 fourth-year students who completed their pre-clinical courses[1], 4 fifth-year students who had just finished their internship in internal medicine[2], and 4 internists with an average of 20 years of experience in internal medicine. The students received a small compensation for their participation.

Material. During observations of patient discussions at three sub-departments of internal medicine (gastroenterology, nephrology and general) the central clinical concepts used in the discussions were noted. The second author of the paper, an internist, classified these concepts either as a symptom, a complex of symptoms referring to bodily function, a complex of symptoms referring to patho-anatomy, or as more generalized, higher order concepts referring to bodily function or patho-anatomy, as a working diagnosis, or as a final diagnosis.

The concepts that were selected for the present experiment concerned the dysfunction of heart, liver and kidneys and addressed the most important underlying pathophysiological mechanisms and the resulting signs and symptoms. Not only higher order encapsulating concepts were chosen, but also some general symptoms, such as edema, in order to chart the knowledge base from different positions. In addition, three concepts that were marked as highly encapsulating and which were often applied by experts in diagnosing a case of acute bacterial endocarditis (Schmidt & Boshuizen, 1992) were included. Finally, four concepts used in a pilot experiment were added and two of them were presented first as practice items. This resulted in a list of 20 experimental items (see table 1).

Procedure. Subjects were told that the experimenter was interested in the meaning they gave to some medical terms. They were instructed to explain each concept in approximately 2 minutes to the experimenter, who should be regarded as a fourth-year medical student. An example made once more clear to the subjects that the experimenter wanted to hear an explanation of the medical term, and how it could be recognized in a patient. The time was set to 2 minutes to prevent subjects from only providing a brief definition of the concept. Subjects were reassured that it did not matter if they had no precise knowledge of all concepts, but were encouraged to say if they did not know a concept or were not sure of their explanation; in the latter cases they were stimulated to guess as well as they could.

In order to prevent that prior activated knowledge had adverse effects on subjects, the presentation order of the first 8 concepts was the same for all subjects; so was the order of the

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[1] Pre-clinical courses are provided within a problem based curriculum.

[2] In the curriculum of the University of Limburg the internship in internal medicine is offered as one of the first three internships. The other two are the internships of surgery and family medicine. The duration of each internship is 12 weeks. Thus, all the fifth year students participating in the present experiment had 12 weeks of experience in internal medicine and 0, 12, or 24 weeks of other clinical experience.

concepts associated with one organ system. The presentation order of the organ systems was balanced to prevent a disproportionate position effect. The explanations were audio-taped and transcribed.

Analysis. The explanation protocols were segmented into small meaningful information units referred to as propositions based on a technique of propositional analysis for medical protocols (Patel & Groen, 1986).

A first parameter in comparing the knowledge of the subject groups concerned the quality of explanations and was operationalized as a score on a scale from 0 to 10: a score of 0 meant that the subject did not know a concept, and could not even make a good guess; a score of 10 meant that the subject gave a complete and coherent explanation; scores from 1 to 9 reflected the relative number and weight of crucial propositions mentioned and the coherence in which this was done. For each item a canonical explanation was constructed which served as a basis for this analysis. The canonical explanations were based on recent medical literature and checked by the second author of this paper. In Appendix A the canonical explanation of the concept of inflammation is provided.

Another parameter was the elaborateness of the explanations which expressed the availability of knowledge. The number of different propositions a subject applied in the explanation was counted, so that propositions which were exactly repeated in the explanation were only counted once. Metacognitive remarks were not included in this analysis and were scored otherwise.

The fluency in which an explanation is provided refers to the availability of knowledge, as well as to the accessibility of available knowledge. This was measured by the number of thinking pauses and the number of remarks referring to a lack of knowledge.

The actual explanation time itself was not analysed as a dependent variable since it was considered as a less reliable variable: Not every subject has the same velocity of speaking, and the same style of explaining.

For each subject the quality scores and the number of concepts were averaged over all items, while the number of thinking pauses and the number of remarks referring to a lack of knowledge were summed up over the items. The data were analyzed by means of ANOVA applying level of expertise as independent variable. The Student-Newman-Keuls test (significance level of .05) was used to make post-hoc comparisons between the three subject groups.

Results and discussion

Quality of explanations. Analysis of the quality of explanations revealed a positive linear effect of level of expertise ($F(2,9) = 23.65$, $p = .0003$): the internists provided better and more complete explanations than the clerks who provided better explanations than the fourth-year

students. The averaged quality scores for each subject group were 8.0, 6.3 and 4.0, respectively. Post-hoc analysis confirmed that all three pairwise comparisons between the subject groups were significant.

Table 1 shows the mean quality scores of the subject groups for the explanations of each concept. Especially students and clerks had the lowest scores for concepts related to the organ system of the kidneys, which indicates that this is a difficult subject for them. Two concepts were unknown for all four fourth-year students, these were passage complaints and uremic complaints. Passage complaints, for example, is a typical clinical (Dutch) concept used in gastroenterology, which is according to one of the internists "reserved to passage complaints of the esophagus, not referring to complaints of swallowing, but the patient feels that the food does not go through the esophagus". Students had never heard the concept before, and the closest guess was "Oh, I think it has to do with constipation in the large intestine", while clerks already picked up the term during their clinical rotations.

Table 1. Mean quality scores (0-10) for the explanations of each concept by fourth-year students, clerks and internists.

Concepts	Mean Quality Scores		
	Students	Clerks	Internists
Inflammation	5.75	6.75	7.50
Thrombo-emboli	6.00	7.25	9.00
Edema	5.75	6.75	7.50
Decreased bodily resistance	6.25	7.25	7.75
Passage complaints	1.25	6.75	8.25
Ascites	3.75	6.75	8.50
Hyperventilation	6.25	6.75	7.75
Sepsis	5.00	6.25	7.75
Forward failure	4.75	6.50	8.00
Congestion of lungs	4.00	7.00	8.25
Right-sided heart failure	5.75	6.75	8.25
Respiratory acidosis	5.25	7.25	8.00
Hepatic encephalopathy	3.00	6.25	7.75
Portal hypertension	6.00	6.50	8.00
Hepatic insufficiency	2.75	6.00	8.00
Uremic complaints	0.75	4.00	8.25
Lower creatinine clearance	2.25	6.75	9.00
Disturbances in calcium and phosphate metabolism	1.75	7.00	7.00
Hypervolemia based on renal insufficiency	1.25	4.25	6.50
Thrombocytopathy	3.25	4.00	8.25

The internists provided better explanations in this sense, that they were more detailed and exact in describing the pathophysiological mechanisms underlying the concepts and that they were generally more complete and coherent in building up their answer. A typical internist's explanation had a clear begin and end, addressing the definition of a concept, the causes and clinical consequences, and often ending with a short summary. This was also true for the good

explanations of clerks, but most students' explanations were not that well organized. Students were rather thinking aloud than explaining and often jumped from one subject to another in their explanations.

Elaborateness of explanations. The elaborateness of explanations as measured by the average number of different propositions applied in the explanations showed a significant main effect for level of expertise ($F(2,9) = 9.64$, $p = .0058$): Internists' explanations were more elaborate than those of clerks', which were more elaborate than students' explanations. Average number of propositions in the explanations was for each subject group, 25.8, 21.4 and 14.6, respectively. Post-hoc analyses revealed that internists and clerks both applied significantly more propositions in their explanations than fourth-year students, while the number of propositions in the explanations of internists and clerks did not significantly differ from each other. These results indicate that both expert physicians and clerks have access to a larger knowledge base than the fourth-year students.

Fluency of explanations. The availability and accessibility of knowledge is indexed by the fluency in which an explanation is formulated. Analysis of the total number of thinking pauses in the explanations revealed a significant main effect for level of expertise ($F(2,9) = 5.91$, $p = .0229$): None of the internists used a thinking pause in their explanations of the 20 concepts, while the clerks and fourth-year students used on average 5.3 and 32.5 thinking pauses, respectively. Student-Newman Keuls tests were significant for the pairwise comparisons of fourth-year students with internists and clerks. The fourth-year students paused when they did not know how to continue and were then obviously searching for the required knowledge in their knowledge base.

Analysis of the total number of remarks referring to a lack of knowledge again revealed a significant main effect for level of expertise ($F(2,9) = 13,41$, $p = .0020$): The internists made just a few remarks that they were not sure since a concept was outside their speciality area (mean of 1.3 remarks), while the average total number of remarks referring to a lack of knowledge was 7.0 for the clerks, and 20.8 for the fourth-year students. Post-hoc comparisons revealed that fourth-year students made significantly more remarks referring to a lack of knowledge than internists and clerks. The fourth-year students were often confronted with the limits of their knowledge in their explanations of the concepts.

These results clearly show that the advanced students have not enough knowledge available to provide coherent and detailed explanations of the concepts in this experiment, and that the required available knowledge is often hard to access.

Summarizing these results, we found that the expert physicians easily provided high-quality, elaborate and fluent explanations of the concepts in this experiment. These findings confirm our hypothesis that the experts are able to unfold their encapsulated knowledge structures whenever

necessary, and that experts have a larger, and better integrated knowledge base than students. Further, we expected that clerks were stimulated to restructure their knowledge by the process of encapsulation during their clinical rotations, because of repeated application of knowledge in dealing with patients. This was evidenced in the present experiment by the finding that clerks provided better, more elaborate and more fluent explanations of the concepts than the fourth-year students; for some concepts the explanations of clerks even equalled those of experts. Although, the fourth-year students completed their pre-clinical courses, it is obvious that they still have to acquire a lot of knowledge and that they have to reorganize their knowledge into easily applicable encapsulating concepts which are used in medical practice. However, the markedly better performance of the clerks in this experiment, suggests that they will be able to accomplish this quickly in their internships.

In addition, we can conclude that the internists are better in explaining their knowledge to somebody else. We expect that this directly results from their more complete and better organized knowledge. Both the clinical experience and the teaching experience of experts will have contributed to the development of their knowledge base. The students in the present study, however, have also experience in explaining medical subjects to each other, since they studied in a problem based curriculum. Through small group discussions they analyzed medical problems attempting to understand the underlying principles or processes.

Research of Chi and colleagues (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, de Leeuw, Chiu, & Lavancher, 1994) showed that the generation of self-explanations improves learning and understanding. Guided by accurate monitoring of their understanding and misunderstanding "good" students spontaneously provided self-explanations while studying worked out examples of mechanics problems (Chi, et al., 1989). Self-explanations, in addition, facilitated the integration of new information into existing knowledge when students where explicitly requested to self-explain in studying expository text on the human circulatory system (Chi, et al., 1994). In medical education, therefore, explaining central medical concepts to themselves and others could not only be a valuable tool for students to assess their own knowledge, but actually contribute to a better understanding of the underlying principles and resulting consequences in a specific domain.

This research was focused on the unfolding of the knowledge base and aimed to discover differences in content and organisation of knowledge between students, clerks and medical specialists. The data analyzed, thus far, seem promising to extend this research with more subjects and a more refined analysis of the kind of concepts applied in the explanations of the different subject groups. Further attempts should be made to untangle the measures of quality and coherence of explanations.

Acknowledgement - Presentation of this paper was partially subsidized by the Limburg University Fund (SWOL).

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Appendix A: Canonical model of inflammation

Inflammation is a reaction of the body (**inflammatory response**) to **tissue injury** .
It is clinically characterized by five **cardinal (local) signs**: the affected area is **red** (rubor), **swollen** (tumor), **hot** (calor), **painful** (dolor), the **function is disturbed** (functio laesa); **systemic manifestations**: **fever** (mediated by interleukines), and increase in the numbers of circulating white blood cells **(leukocytosis)**.

Causes of tissue injury:

Mechanical trauma, such as cutting or crushing
Chemical injuries, such as those produced by acids, alkalis and phenols An important cause is the presence of physiological substances in inappropriate locations.
Injury due to extremes of cold or heat (burns and frostbite)
Injury caused by living organisms such as bacteria, viruses, parasites, worms and fungi.
Ultraviolet or x-irradiation
Internal injuries: injury due to a degree of reduction in the arterial blood supply sufficient to cause death of the underperfused tissue; injury produced by the inappropriate or excessive operation of immune mechanisms.

Inflammation response:

Occurs within the microvasculature at the level of the capillary and post capillary venule. Specific inflammatory mediators produced at the sites of injury regulate the response of the vasculature to injury.

Vasoactive mediators --> **vasodilatation** --> redness and warmth
increased blood flow and **an increase in permeability of the vessel walls** (loss of integration of endothelial cells)
--> **increased leakage of fluid** from the intravascular compartment into extravascular spaces --> edema --> swelling
--> **local stasis**
Chemotactic factors are generated that recruit white blood cells (**recruitment of stimulation of inflammatory cells**) from the vascular compartment into the injured tissue.

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